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Earth Winds, Flow Quality, and the Minimum-Protection Inlet Treatment for the NASA Ames 80- by 120-Foot Wind Tunnel Nonreturn Circuit

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Command

NOTATION

A cross-sectional area of test section

D_h hydraulic diameter of test section, 4 A/P

P perimeter of test-section cross section

V_o mean test-section airflow velocity, m/s (knots)

Δ_u maximum axial velocity deviation, due to wind effects, from the mean test-section airflow velocity (measured over central 47% of test-section area), m/s (knots)

Δ_v maximum lateral velocity deviation, due to wind effects, from perfect axial flow (positive starboard) (measured over central 47% of test-section area), m/s (knots)

Δ_w maximum vertical velocity deviation, due to wind effects, from perfect axial flow (positive up) (measured over central 47% of test-section area), m/s (knots)

ψ azimuthal angle of model centerline with respect to wind axis (positive for wind from port), deg

EARTH WINDS, FLOW QUALITY, AND THE MINIMUM-PROTECTION INLET TREATMENT FOR THE NASA-AMES 80- BY 120-FOOT WIND TUNNEL NONRETURN CIRCUIT

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SUMMARY

NASA is currently modifying the Ames 40- by 80-Foot Wind Tunnel to include a new 24- by 37-m (80- by 120-ft) test section in a nonreturn circuit. A major concern for this new facility, as for any wind tunnel with an open inlet, is the effect of the external wind on the quality of the flow in the test section. While an effective but complex inlet-protection system has been developed, the Modification Project Plan calls for a more economical, minimum-protection system for the open inlet. This report discusses the flow quality achievable with the complex treatment as well as that with the planned minimum-treatment system. A scale-model experimental program, coupled with on-site wind measurements, has demonstrated that the minimum treatment selected can provide adequate testing capabilities in the presence of the prevailing local winds, and that test programs will not be significantly affected by adverse wind effects on test-section flow quality.

BACKGROUND

The record of aeronautical contributions over the past 35 years has proven the value of full-scale aerodynamic testing and of the Ames 40- by 80-Foot Wind Tunnel. Recent interagency studies have shown the need for major improvements to full-scale testing capabilities. Specifically, the need lies in the areas of increased test-section size and airspeed. Design studies determined that the most cost-effective means for achieving the desired improvements were the repowering and expansion of the existing 40- by 80-Foot Wind Tunnel (see refs. 1 and 2).

Figure 1 shows the planned modifications. Repowering the drive system from 27 to 100 MW (36,000 to 135,000 hp) will increase the maximum airspeed in the test section of the existing, closed-return circuit from 100 to 150 m/s (200 to 300 knots). A larger test section, 24 by 37 m (80 by 120 ft), specifically designed for V/STOL testing, will be added in a new, nonreturn-flow test leg with an open inlet facing northwest.

The nonreturn circuit was selected over a closed circuit after careful consideration of the relative merits of aerodynamic/energy efficiency, protection of internal flow from external winds, community noise and visual impact, and construction costs. The simplicity and economy of the open inlet were the primary points in its favor. The effects of the local wind on testing capability and programs, as measured by the test-section flow quality (uniformity), were a major concern due to their impact on the ultimate utility of the new addition.

In order to properly address this concern and answer its related questions, the flow-quality/wind-effects problem was approached systematically in three parts. First, flow-quality criteria for aeronautical testing were evaluated and a set of criteria appropriate for V/STOL testing was developed. Second, scale-model studies determined the wind sensitivity of various inlet-protection devices. And third, wind measurements at the Ames site defined the environment in which the new, nonreturn facility would have to operate. The conclusion obtained from these studies is that an economical inlet system can be used without significant penalties in flow quality in the test section.

This report summarizes these development and analysis studies. It also documents the expected flow-quality performance of the selected inlet treatment along with the predicted impact on facility operations due to wind effects on test-section flow quality.

FLOW-QUALITY REQUIREMENTS

After careful study of the unique requirements of V/STOL aircraft operation and testing, criteria were established (ref. 3) for the flow quality required in any such aeronautical testing facility, whether open- or closed-return. The very simple criteria are shown in figure 2. Lateral- and vertical-velocity deviations from the mean, no-wind condition are restricted to ±0.25 m/s (±0.5 knots). Axial-velocity deviations have the same restriction up to test speeds of 50 m/s (100 knots), beyond which the deviations may be no greater than 0.5% of the test speed. It was these criteria against which the inlet-protection systems and wind effects were evaluated.

MODEL STUDIES

Using the minimum acceptable flow quality (defined by the criteria of ref. 3 and fig. 2), an extensive series of model tests was undertaken to compare and evaluate the relative merits of various amounts and types of inlet treatment in the presence of a wide variety of wind conditions. Powered models of nonreturn-flow facilities were placed in the existing test section of the 40- by 80-Foot Wind Tunnel which was used as the wind source. (Figure 3 shows one such model, a 1/50-scale simulation of the modified facility.) Then, by varying the relative flow speeds of the model and "wind" and by changing model orientation, the effects of different winds for the several configurations were measured.

These studies involved only the effects of steady-state winds with a uniform velocity distribution. It was concluded from other studies (refs. 4 and 5) that the steady-state wind was the critical problem and that wind gusts produced only a small effect on the turbulence of the test-section flow. Limited studies were performed with the model on the floor and the boundary layer artificially thickened to simulate the Earth's boundary layer for wind over flat, open country (ref. 6). These studies indicated that the velocity profile was not important and that a uniform velocity equal to that at the wind-tunnel centerline could be used to establish wind effects on the test-section flow quality.

Many inlet configurations were tested in the experimental program which have been reported in references 7 through 9. The most effective treatment system developed for a horizontal inlet is shown in figure 4(a). This inlet treatment, discussed in greater detail in reference 3, incorporated a large screened "room" with a solid roof, supported by aerodynamically faired and aligned posts and two sets of flow-straightener grids. As shown in figure 4(b), this system provided good protection, meeting all criteria, from 5 m/s (10 knots) winds for test-section flow speeds as low as the same 5 m/s (10 knots).

This highly developed treatment was almost as complex as it was effective and a simpler inlet protection was desired. The selected inlet configuration, shown in figure 5, is relatively simple, having no shielding upstream of the contraction inlet face. It has only a combination flow-straightener, acoustic-baffle grid, and a bird screen at the inlet of a five-to-one area-ratio contraction.

Wind sensitivity of this minimum-protection inlet was studied extensively. Representative results are shown in figure 6. As shown in figure 6(a), the flow quality was good at a wind speed of 5 m/s (10 knots) and for many directions of wind. For a few conditions, the flow-quality criteria were exceeded. Figure 6(b) gives a more pictorial look at this inlet's tolerance to external wind. There is a significant region where winds up to 10 m/s (20 knots) within about 5° from the inlet centerline are acceptable. A larger quadrant of wind may be acceptable, within the criteria, depending on the particular requirements and test envelopes of specific wind-tunnel programs. The rest of the possible wind conditions would be "acceptable" only with relaxed flow-quality criteria and reduced data accuracy.

The series of model studies determined the wind conditions under which an open wind-tunnel inlet, particularly one with minimum protection, might operate productively. However, the ultimate acceptability of the selected inlet design was dependent on the actual wind conditions at the Ames site. Therefore, long-term measurement of the prevailing winds at the site was undertaken.

SITE STUDIES

Wind measurements were taken at the site of the planned facility extension for integration with the model wind-tunnel test results. A tower was erected

at the location of the inlet face. Propeller-driven sensors were placed at the quarter-height points of the inlet. (The inlet centerline will be at the 18-m (60-ft) elevation.) Data were recorded at the site for a period of about 2 years.

The measured wind direction and time patterns are shown in figure 7(a). For the summer and fall months (represented by August and November), the predominant wind is from the northwest quadrant. In the winter (February), south and southeast winds increase during stormy weather, and in the late spring (May), there is a significant increase of north winds. Regardless of the time of year, however, the wind-speed patterns are very similar from day to day. As figure 7(b) shows, the mean wind speed always peaks at a relatively low level around mid-afternoon, gradually building before and decreasing after the peak. Thus, the winds at Ames are generally predictable and relatively low in magnitude and often from the northwest quadrant. These and other more detailed site-wind data gave a good understanding of the wind conditions to be expected during the future operation of the facility.

IMPACT OF WINDS ON TESTING PROGRAMS

The combined data from the model and site studies showed that the planned minimum-protection wind-tunnel inlet in the presence of the observed Ames winds will achieve an acceptable level of flow quality in the new V/STOL test section. Figure 8 shows the average available testing time as a function of time of day. Generally, about 25% of day- and swing-shift working hours is required for actual tunnel-on testing. (The balance of the time is devoted to model preparation, instrumentation checkout, and configuration changes.) For the majority of the year, the time of acceptable winds (i.e., with test-section flow quality within the criteria of ref. 3 and fig. 2) well exceeds the time required. Only in the spring would wind be likely to impact the test schedule. However, even in the spring most wind-effects problems should be overcome by careful scheduling.

CONCLUDING REMARKS

External winds are real and potentially severe concerns for nonreturn wind tunnels; however, various protection systems have been developed which minimize the effects of large winds on test-section flow quality. Fortunately, Ames Research Center has relatively low and predictable winds in which to operate the Ames 40- by 80-/80- by 120-Foot Wind Tunnel. A combination of model and site-wind studies has demonstrated that, even with minimal inlet protection, this facility should still prove to be an extremely valuable aeronautical tool under most wind conditions. Schedules will be modified as much as possible to avoid winds that are not protected against. Further, should testing, program, or facility schedule requirements change so that more effective inlet treatment is needed in the future, that technology now exists. Significant additional inlet-wind protection can be retrofitted, if necessary,

to assure maximum utilization of this facility with essentially no impact of external wind conditions on flow quality in the test section.

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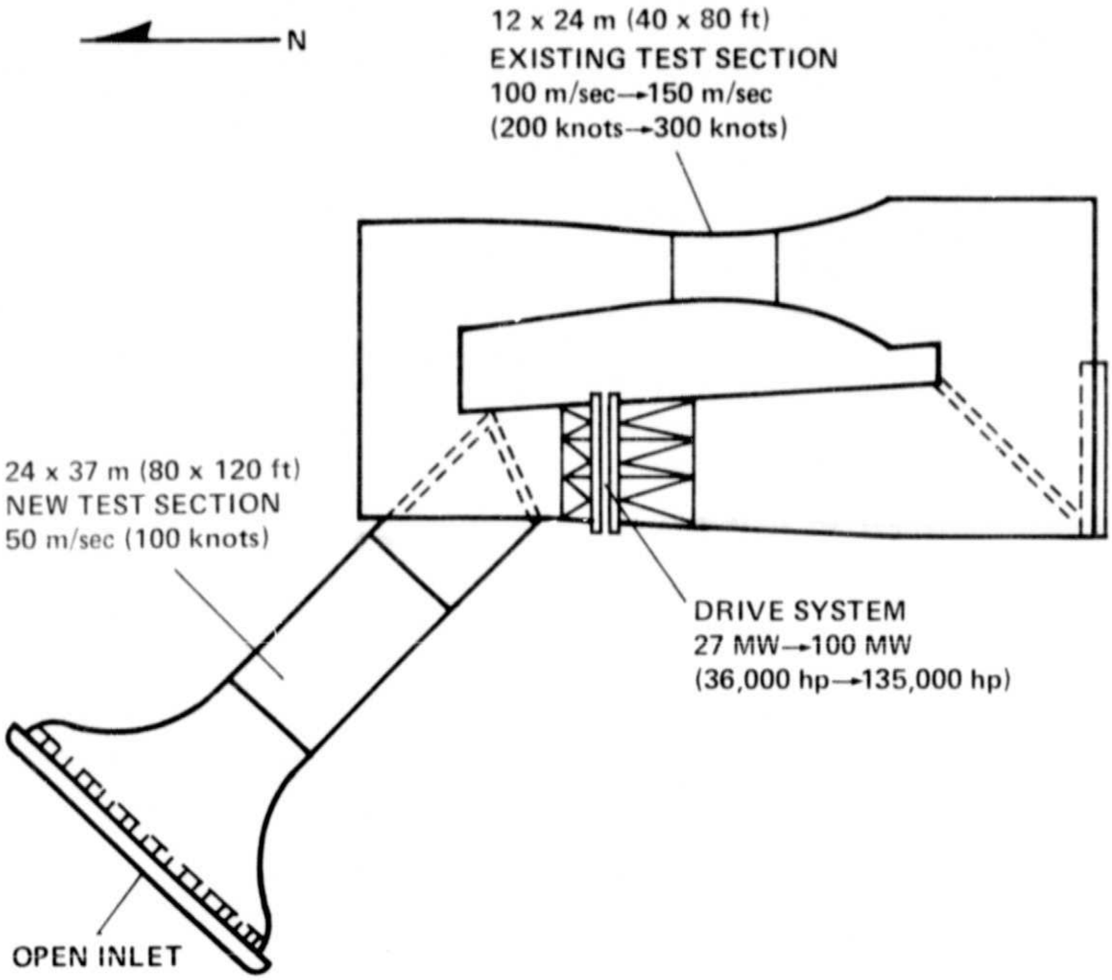


Figure 1.- Modifications to the Ames 40- by 80-Foot Wind Tunnel.

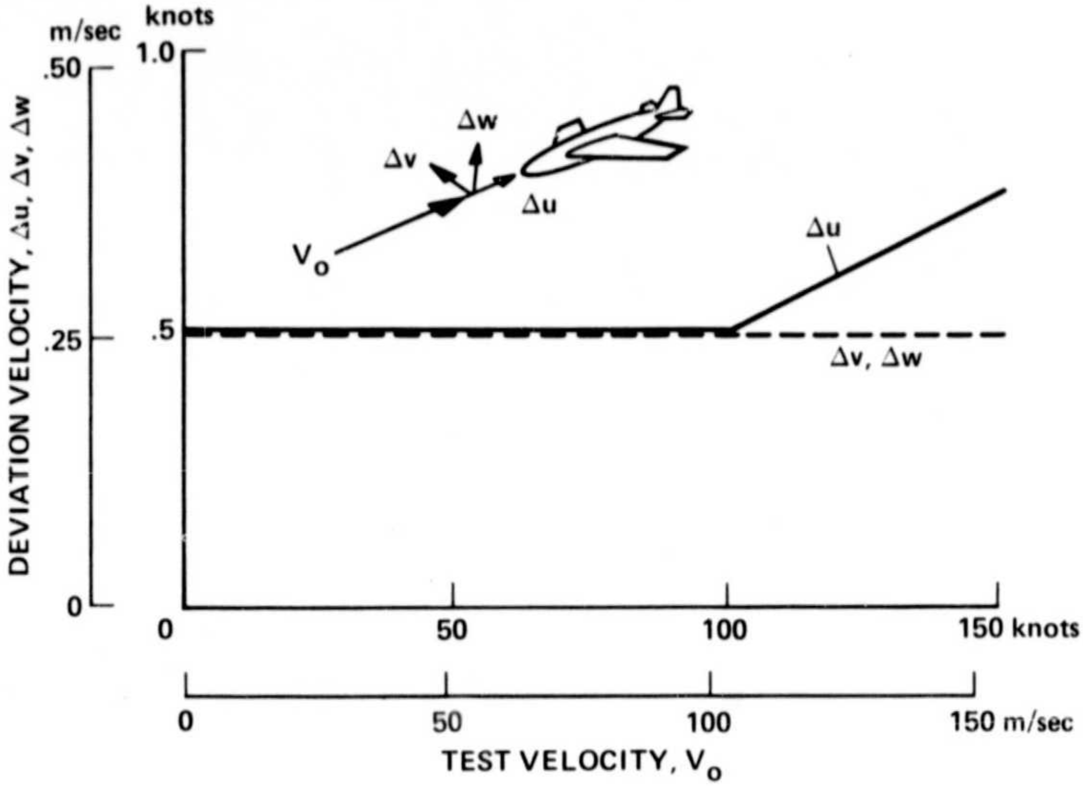


Figure 2.- Flow-quality criteria for V/STOL testing (from ref. 3).

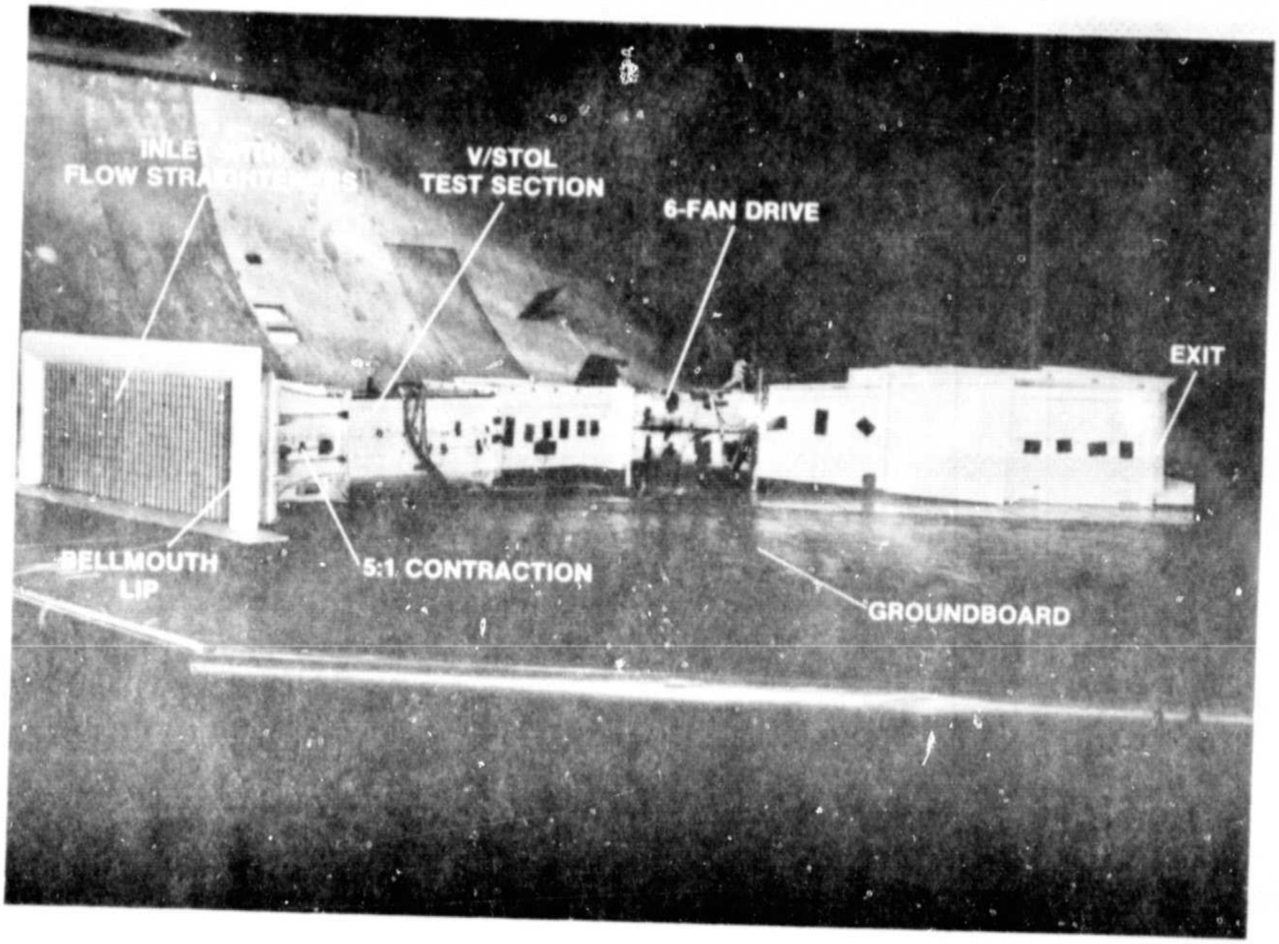
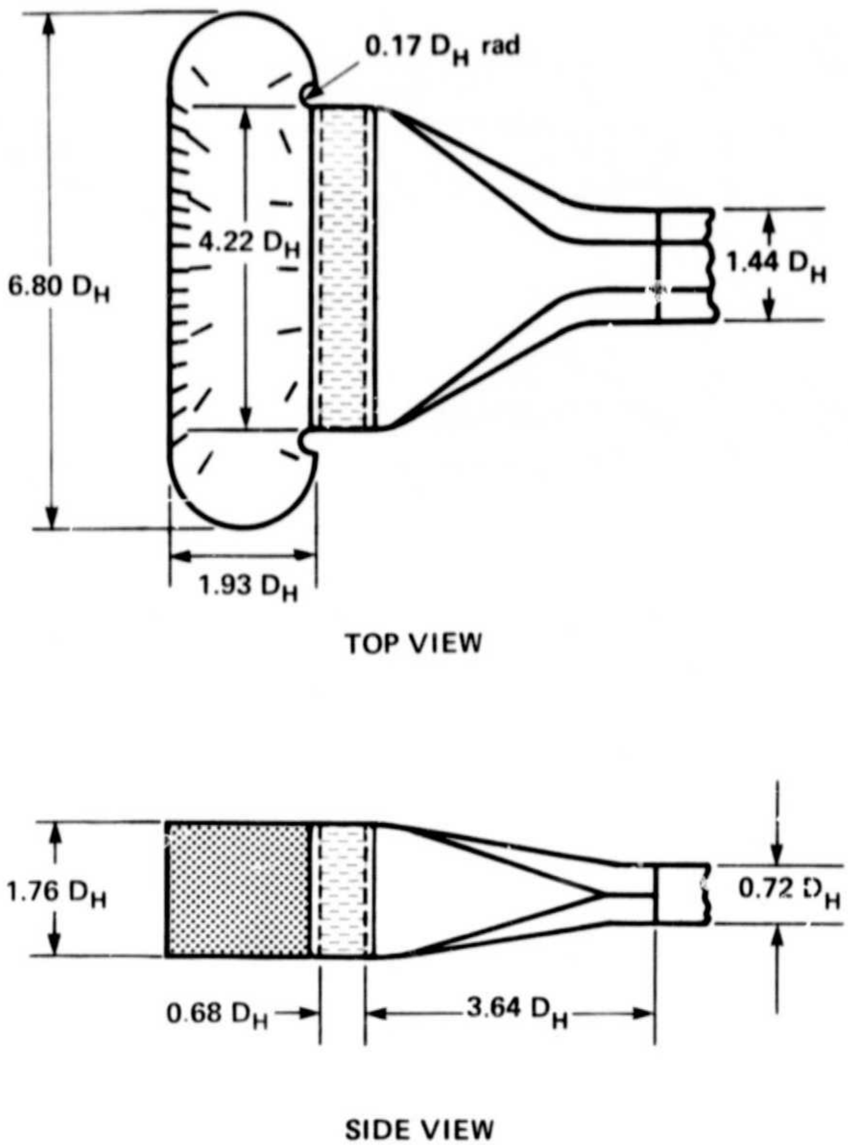


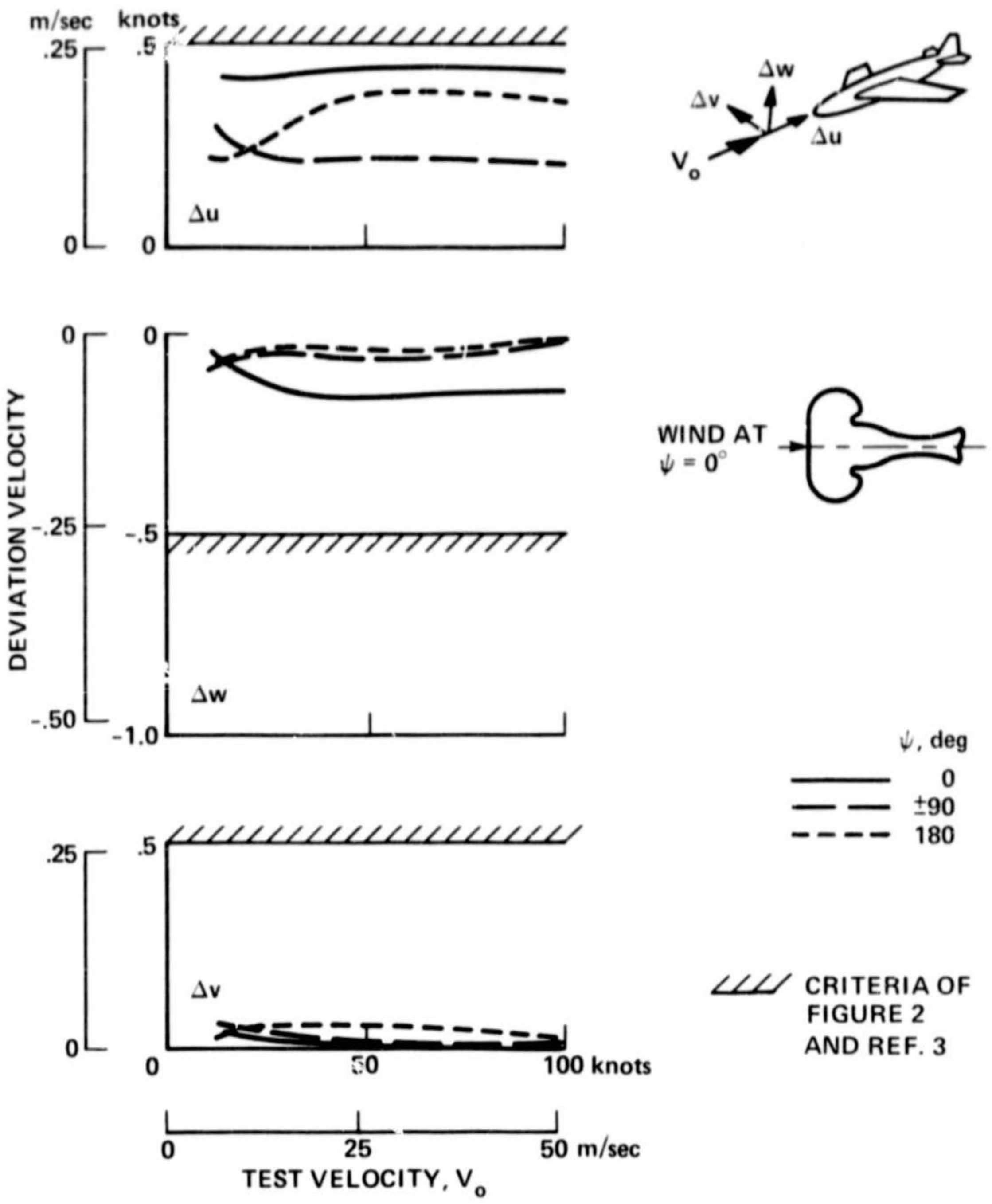
Figure 3.- 1/50-scale model of modified facility with minimum-protection inlet installed in Ames 40- by 80-Foot Wind Tunnel.



CONTRACTION RATIO: 8:1
D_H = HYDRAULIC DIAMETER OF TEST SECTION

(a) Geometry of treatment.

Figure 4.- Developed, complex inlet-protection system.



(b) Measured inlet performance at a wind speed of 5 m/s (10 knots).

Figure 4.- Concluded.

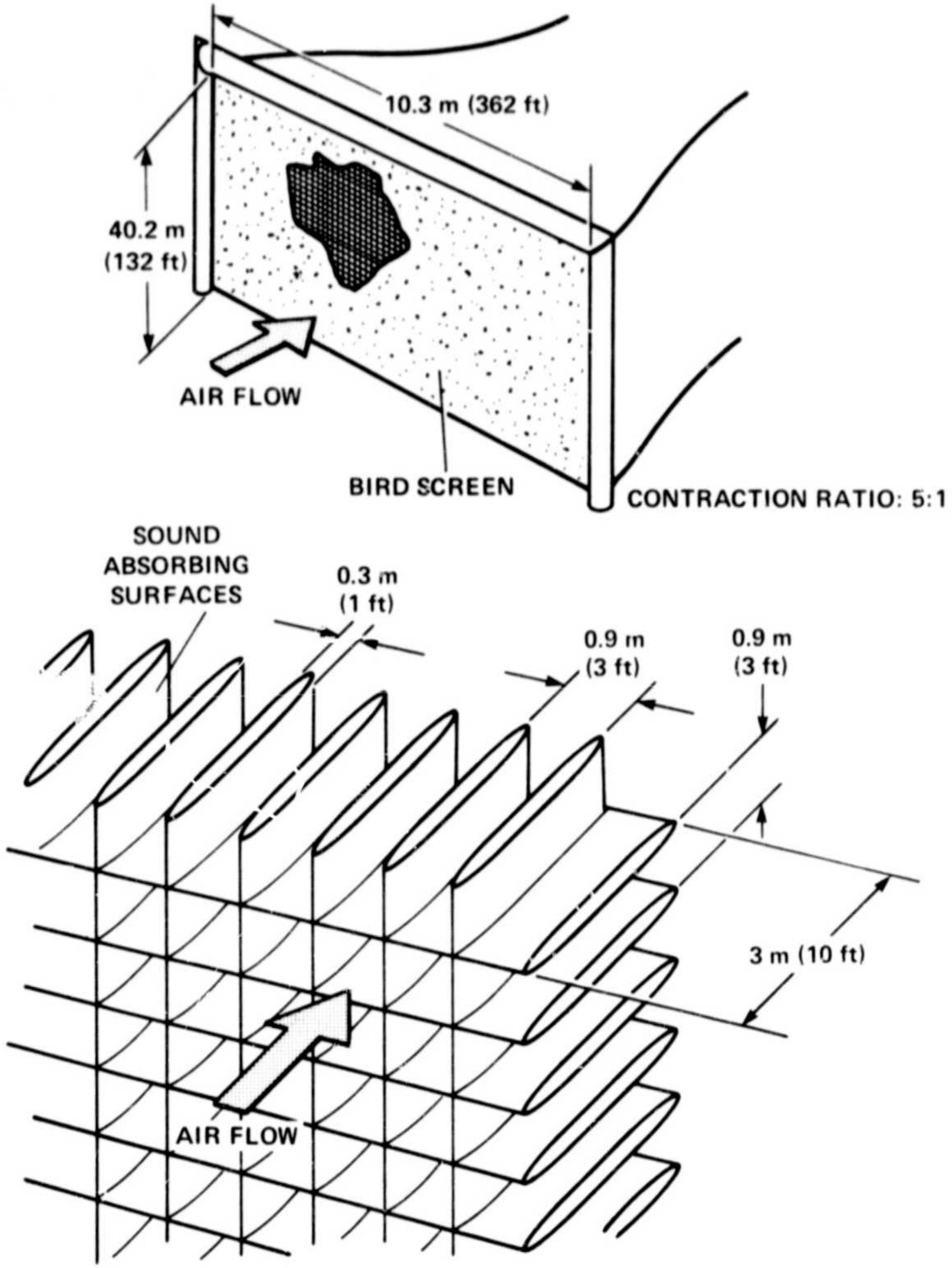
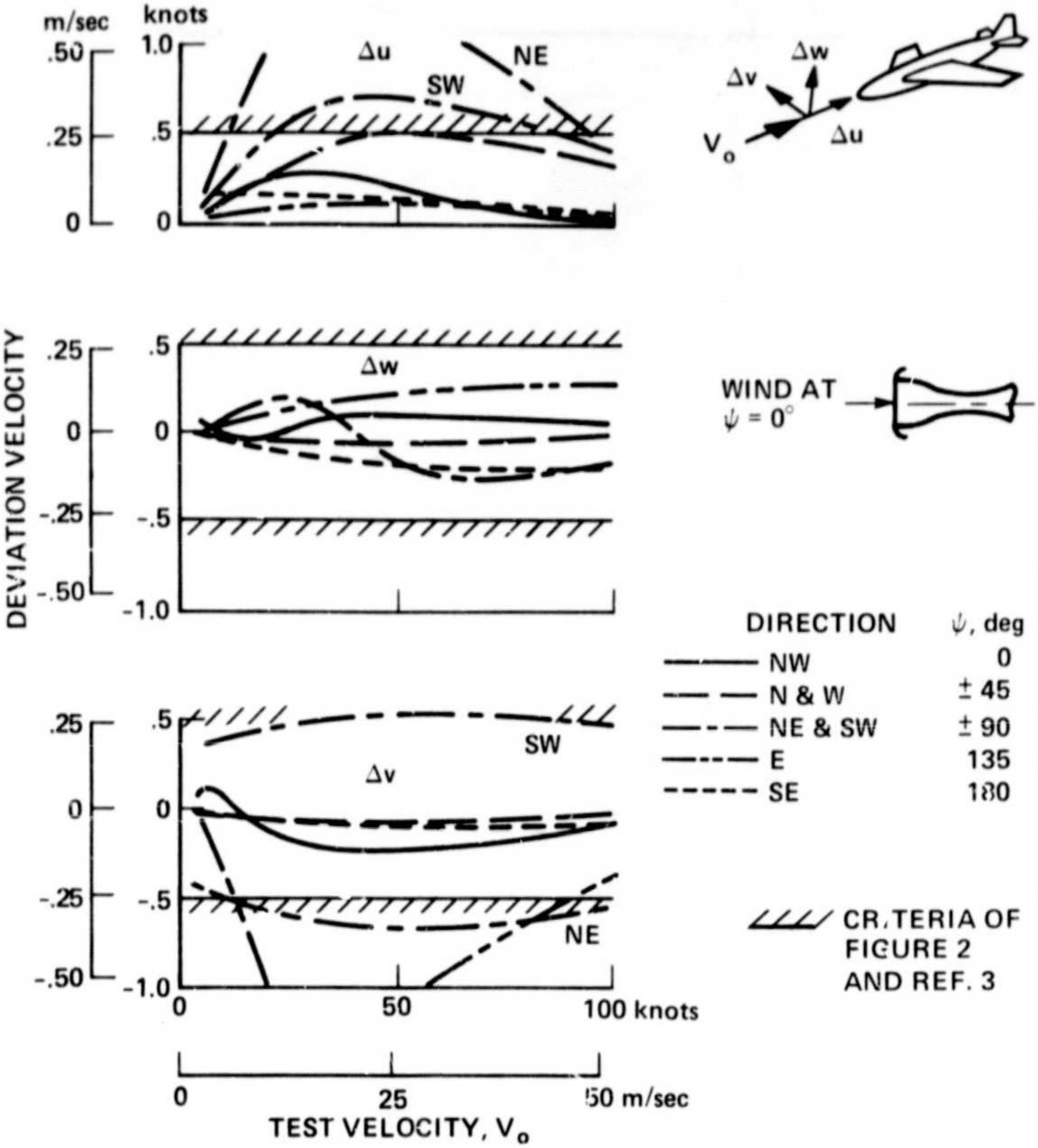


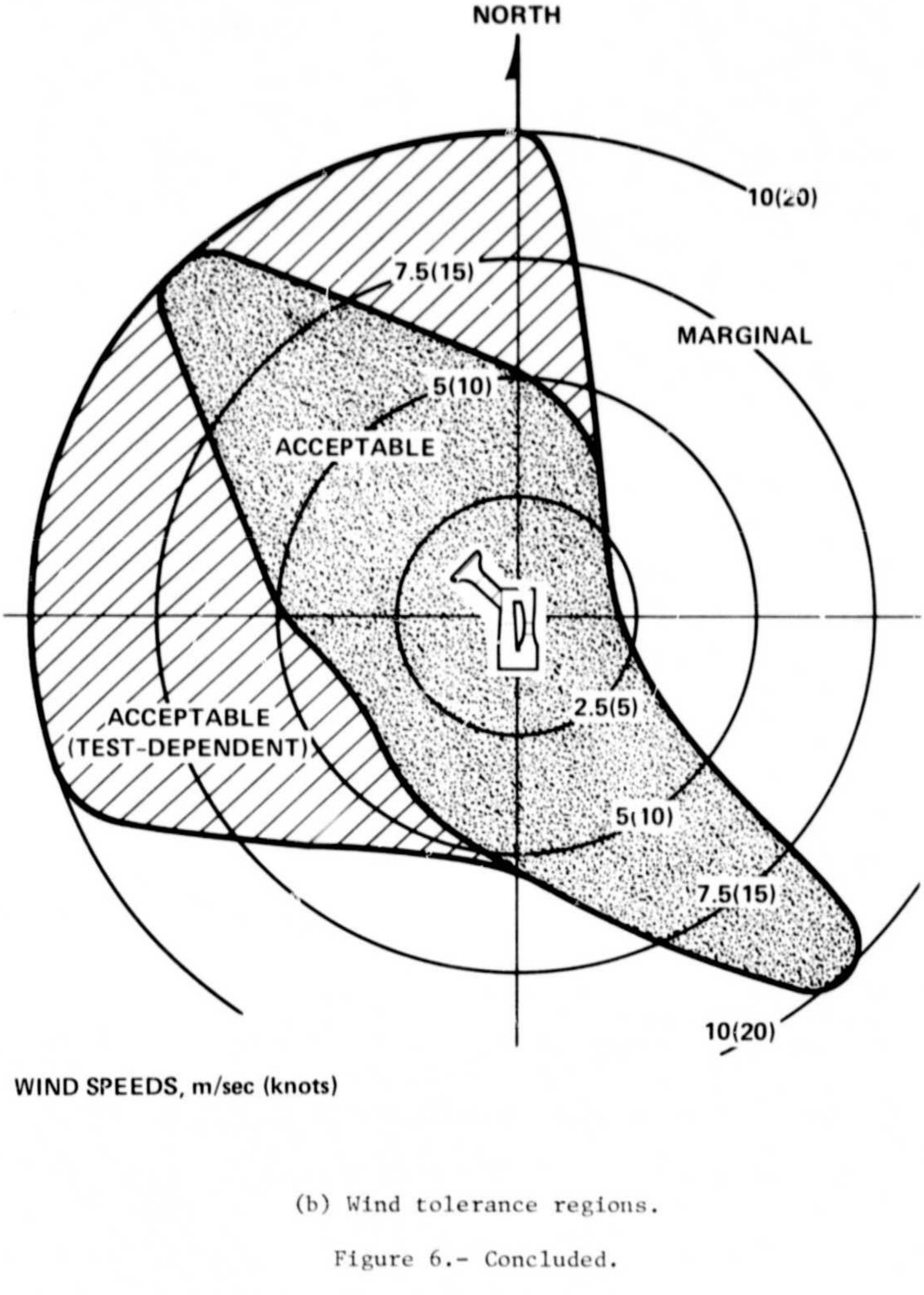
Figure 5.- Flow-straightener and acoustic-baffle system of selected inlet treatment.



(a) Measured deviation velocities in the presence of 5 m/s (10 knots) winds.

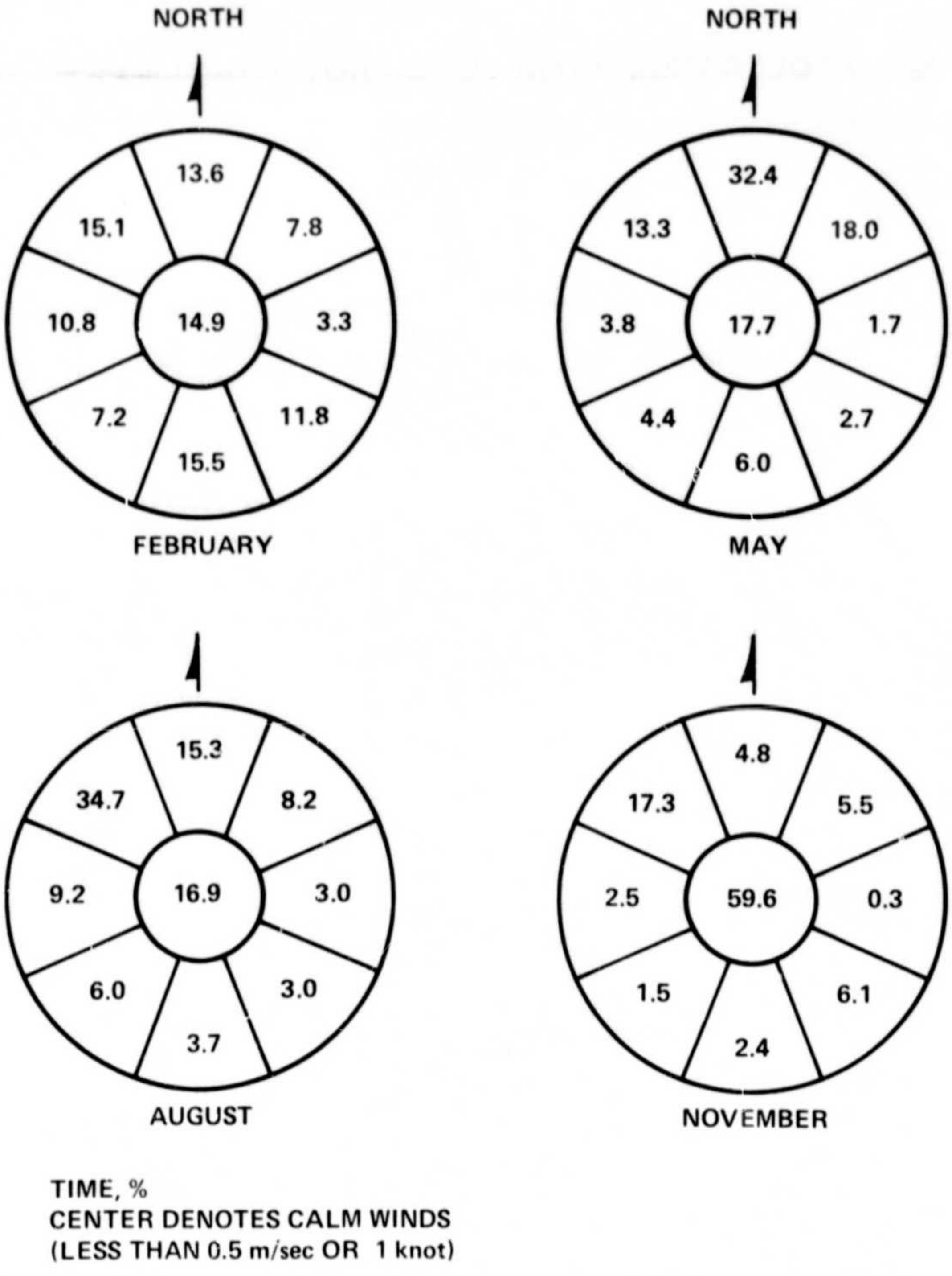
Figure 6.- Performance of minimum-protection inlet system.

WIND TOLERANCE OF MINIMUM-PROTECTION INLET



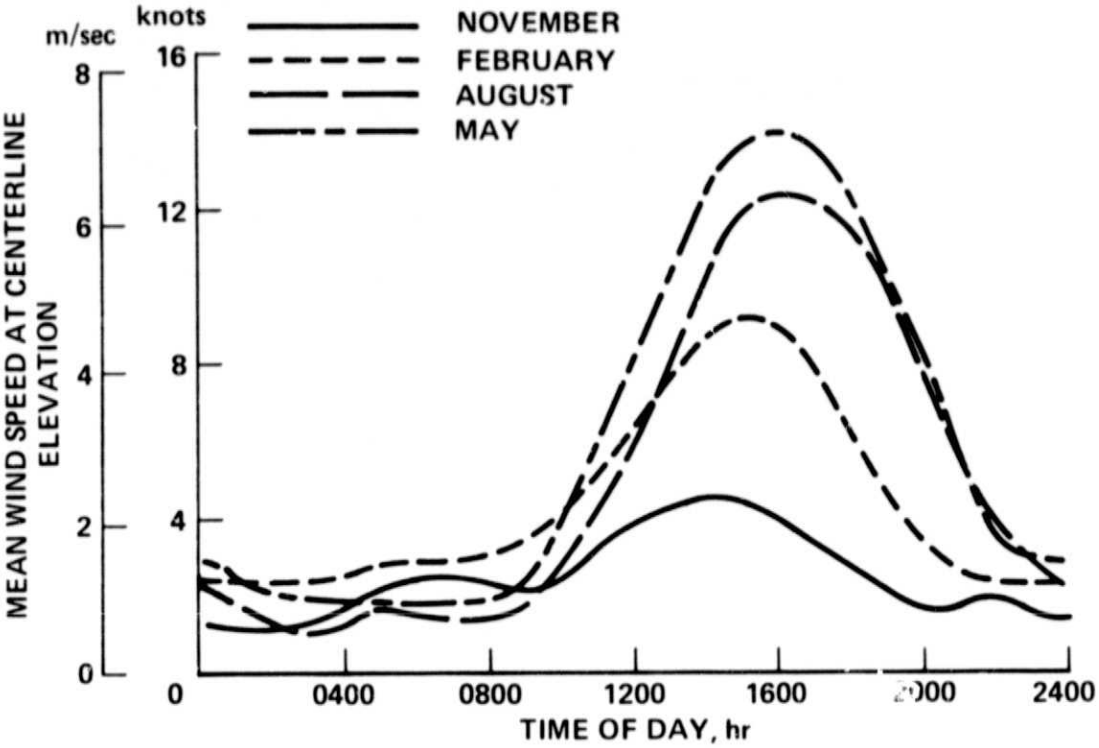
(b) Wind tolerance regions.

Figure 6.- Concluded.



(a) Wind roses showing direction-time patterns.

Figure 7.- Wind patterns at facility site, elevation 18 m (60 ft).



(b) Day-to-day repeatability of wind velocities.

Figure 7.- Concluded.

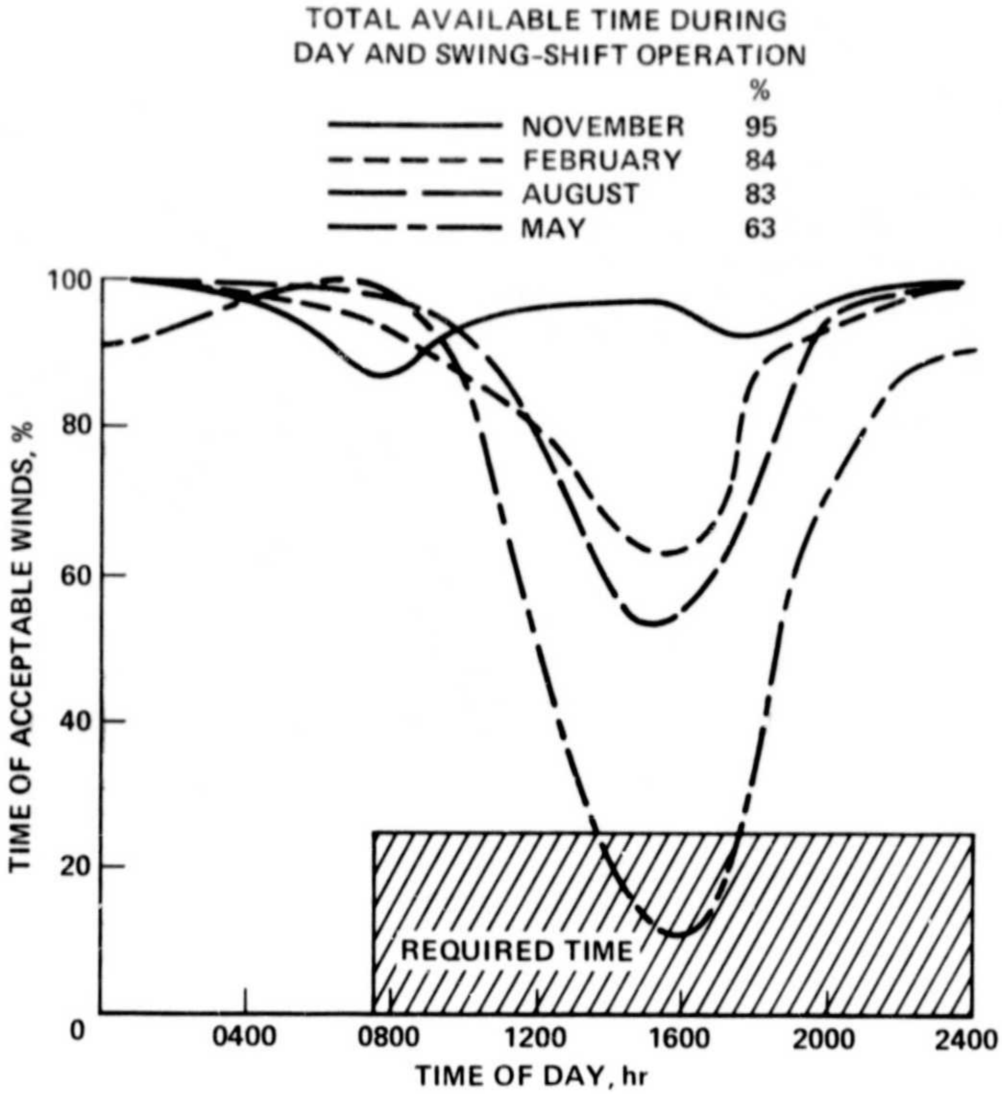


Figure 8.- Impact of Ames winds on available testing time in new nonreturn circuit.

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16. Abstract

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